The Coordinated Control of a Central Air Conditioning System Based on Variable Chilled Water Temperature and Variable Chilled Water Flow

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Abstract: At present, regulation of water flow by means of pump frequency conversion is one of the major methods for power-saving in central air conditioning systems. In this article, optimization regulation for central air conditioning system on the basis of coordinative optimization control for variable chilled water temperature and variable chilled water flow to obtain better power savings is put forward. According to typical meteorological year data, hourly air conditioning load of whole year for every typical room has been calculated with the transmission function method. In order to guarantee each typical room, the highest cooling load rate is used as an input parameter for optimization calculation. Based on the surface cooler check model, the smallest energy consumption of chiller and chiller water pump was taken as the objective function of the optimization model. The performance characteristics of a chiller, water pump, regulation valve and pipeline are taken into account, and the optimization chilled water temperature and chilled water flow were carried out. The case study for a commercial building in Guangzhou showed that the annual power consumption of the chillers and pumps of the air conditioning system is lower by 17% only with employment of variable water flow regulation by pump frequency conversion. In the case of optimization control with coordinative control of variable chilled water temperature and variable chilled water flow, the annual power consumption of the chillers and pumps of the air conditioning system is reduced by 22% in presence of remarkable power saving effects. Increasing the chilled water temperature will reduce the dehumidified capability of the air cooler, and the indoor relative humidity will increase. The simulation showed that the adjustment optimized process meets the comfort of each typical room. The lower the cooling load rate is, the more obvious the effect of power-saving is. The highest power-saving rate appears in December, which is 36.7%. Meanwhile, the least rate appears in July, which is only 14.5%.

Keywords: variable chilled water temperature adjustment; water pump frequency conversion; air conditioning load; comfort air-conditioning; power saving

1. FOREWORD

In recent years, electric supply has been in great shortage in many cities with development of economics in China while the electricity consumption has been soaring up by years, the power of saving is in urgency. With rising of electricity price, a lot of building owners had improved their air conditioning systems for power saving by means of installation of transducer for frequency conversion of chilled water pumps. The adjustment of chilled water system can be mainly divided into two types: quantitative adjustment and qualitative adjustment, water pump frequency conversion belongs to the former, variable chilled water temperature belongs to the latter. Adjustment of variable chilled water temperature is to increase chilled water outlet temperature under partial loading condition so as to get target of power saving of chiller. The feasibility and economic study of variable chilled water temperature have been analyzed and discussed in the reference [1]. The modeling calculation with effective combination of two means demonstrated regulation process and power-saving effect.

2. CALCULATION OF HOURLY AIR CONDITIONING LOADS OF WHOLE YEAR AND CONFIRMATION OF THE HIGHST LOAD

The detailed data of the cooling load of air conditioning system is primary dependence for the power-saving operation in air conditioning system. Only cooling load pattern for every air-conditioning room is comprehended, are both the comfort of every room and energy saving of the air conditioning system satisfied. With the transmission function method for cooling load, [2] the whole year hourly cooling loads of typical rooms in a commercial building in Guangzhou was calculated.

Meteorological data come from the literature [3], which provides typical meteorological database of Guangzhou city. The heat and moisture gain from persons and equipment were calculated on basis of rated value.

According to the design standards for heating, ventilation and air conditioning, the design cooling load is greatest one but annual 50-hour, and multiplied by 1.1 times assurance factor to choice air cooler, i.e. the loading rate at optional moment in optional room is available to be shown with the following formula:

$$\text{Loading rate} = \frac{\text{real cooling load}}{1.1 \times \text{design cooling load}}$$

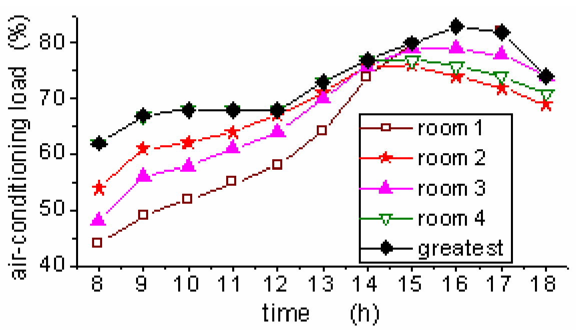

Fig.1 Confirmation of the greatest load rate

To meet the comfort of every room during optimum adjustment process, the highest cooling load rate was used for input data, the method to determining the highest cooling load rate is shown in figure 1. The cooling load frequencies of room 1 and the highest cooling load frequency are shown in table 1, the statistical time for air-conditioning operation time is from March to December, 8:00 A.m. to 6:00 P.M.

3. SIMULATION OF COORDINATIVE OPTIMIZATION REGULATION FOR ANNUAL VARIABLE CHILLED WATER TEMPERATURE AND VARIABLE CHILLED WATER FLOW

3.1 The Simulation Model of the Coordinative Optimization Regulation for Variable Chilled Water Temperature and Variable Chilled Water Flow in Air Cooler

Based on the highest cooling load rate and the corresponding meteorological parameters, the calculation method of heat transfer efficiency coefficient ε_1 and contact coefficient ε_2 were adopt, the calculations process is showed in Figure 2, the whole year hourly chilled water flow, outlet temperature, and indoor relative humidity are carried out. For JW104 model with a 6 rows surface-type air cooler, the process diagram showed in Figure 2， hourly cooling water flow, outlet temperature and indoor relative humidity of the whole year are carried out.

Such calculation model is used for the primary return air air-conditioning system, the design condition in Guangzhou is as followings: outdoor air-conditioning design parameters for dry-bulb temperature is t_W=33.5 ℃, relative humidity is φ_W=64.8%; indoor temperature parameters for dry-bulb temperature is t_N=25 , relative humidity is φ_N =50%; chilled water outlet temperature is t_{w1}=7, return temperature is t_{w2}=12 ; chilled water velocity is w =1.4m/s; fresh air proportion is m%=20%. Keep the indoor dry-bulb temperature t_N, wind rate G, fresh air proportion m% and indoor angle scale constant.

Tab.1 Air conditioning cooling load time frequency(%)

Load percentage	10	20	30	40	50	60	70	80	90	100	>100

Accumulated loading time in room 1	5.0	11.7	19.7	30.6	43.5	60.2	80.8	92	98.1	100	100
Most disadvantageous load	0.8	3.3	9.4	17.3	27.6	41.5	63.1	83.4	96.7	99.9	100

During calculation process of air data, IDG Graph Control was used.

The supply air dry-bulb temperature is:

$$t_2 = t_{s2} + (t_1 - t_{s1})/(1-\varepsilon_2);$$

Actual angle scale:

$$\varepsilon' = 1000 \times (i_N - i_2)/(d_N - d_2);$$

The performance parameters a air cooler:

The dehumidification factor: $\xi = \dfrac{i_1 - i_2}{C_p(t_1 - t_2)}$;

Heat transfer coefficient::

$$\mathrm{K} = \left[\frac{1}{41.5V_y^{\ 0.52}\xi^{1.02}} + \frac{1}{325.6w^{0.8}}\right]^{-1};$$

Heat transfer unit number: $\beta = \dfrac{KF}{\xi G c_p}$;

Water equivalent proportion: $\gamma = \dfrac{\xi G c_P}{W\mathrm{c}}$.

Air cooler heat transfer efficiency:

$$\varepsilon_1 = \frac{1 - e^{-\beta(1-\gamma)}}{1 - \gamma e^{-\beta(1-\gamma)}}$$

Chilled water temperature:

$$t_{w1} = t_1 - (t_1 - t_2)/\varepsilon_1$$

The rated input power of chiller is P_C =268kW, the rated input power of all of the chilled water pumps and cooling water pumps are P_P =35kW. The chilled water temperature rises 1 ℃, the COP of the chiller will be improved to 2% to 3%.[1] The COP data of a chiller provided by the reference [1] and [5] shows that the chilled water temperature rises 1 ℃, the COP of the chiller will be improved to 2% to 3%. In this article, assumption in which every rising of 1 of chilled water temperature, power saving of chiller will reach 2.5% was used for an estimation of power-saving during variable chilled water temperature regulation. Without consideration for COP of the chiller with change of load, the power saving of chiller can be expressed by:

$$\theta_C = 2.5\% \times (Q/Q_0) \times (t_{w1} - 7)$$

Where: Q/Q_0 is cooling load rate.

According to pump analogical law, the pump power–consumption is in proportion to the cube of the water flow, and pump power–saving rate of pump can be expressed as follow:

$$\theta_P = n \times [1 - (W/W_0)^3]$$

Where: n is a correction factor relating to the shape and function of the buildings; in this article n=0.8 is used and W/W_0 is the percentage of the water flow.

The cooling water flow is in proportion to the cooling road rate, as the cooling water temperature difference between outlet and inlet of the chiller is constant by pumping frequency conversion for a cooling water system.

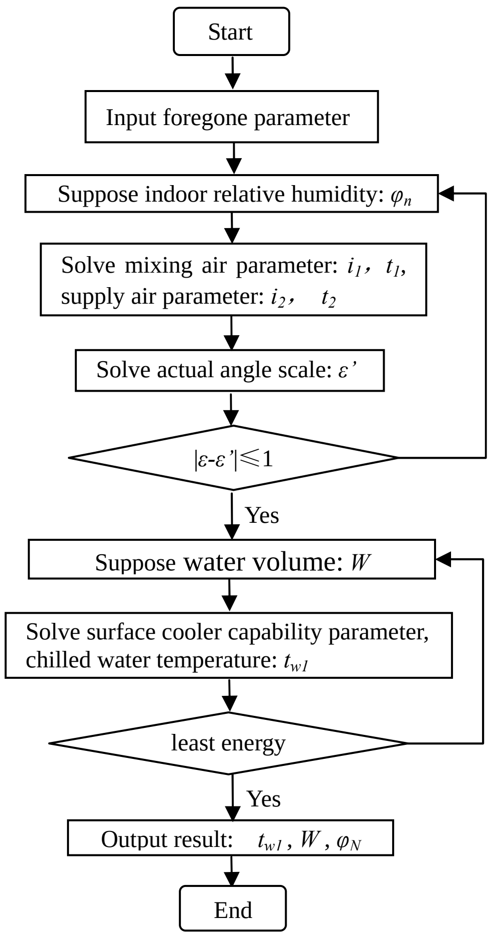

Fig.2 Optimization calculation flowing diagram

To ensure operational security of the system, the smallest flow of chilled water and cooling water are 60% of the design value, and the corresponding pump frequency is 30Hz. The lowest chilled water temperature is 7.0℃, and the highest one is 15.0℃. Such 7.0℃ and 15.0℃ are two chilled water temperatures used for inspection for air cooler performance by Nation Air Conditioning Equipment Supervision Testing Center.

3.2 Actual Calculation and Analysis of Case Study

Case study results for a commercial building in Guangzhou were showed from figure 3 to figure 8. From March to July, as the cooling load gradually increasing, the chilled water flow gradually increases, while the outlet of chilled water temperature gradually reduces. During air conditioning system operation time from 8:00 AM to 6:00 PM, the cooling load rate is generally high in middle time and low in the two ends of the time, so did chilled water flow but contrary to the temperature of the outlet. Some exception existed; for example, on March 20th, the gradual lowering of outdoor temperature resulted in gradual reduction of cooling load at that day. It is noteworthy that in case of lower cooling load, chilled water flow was at its small limit, which shows limitation as adoption of only pump frequency conversion.

It shall be pointed out that the cooling load rate is the main factor to affect the chilled water flow and outlet temperature, but not the only factor,. The outdoor dry-bulb temperature and relative humidity will also affect to them.

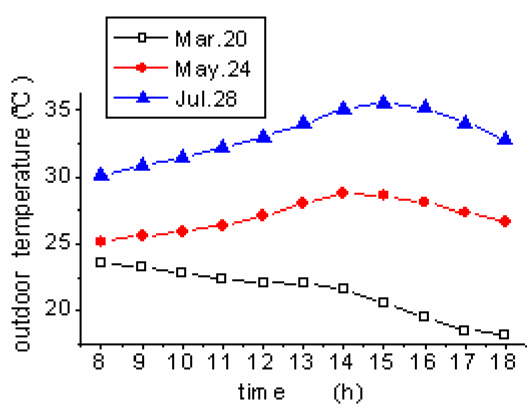

Fig.3 Variations of the outdoor dry-bulb temperature with respect to time

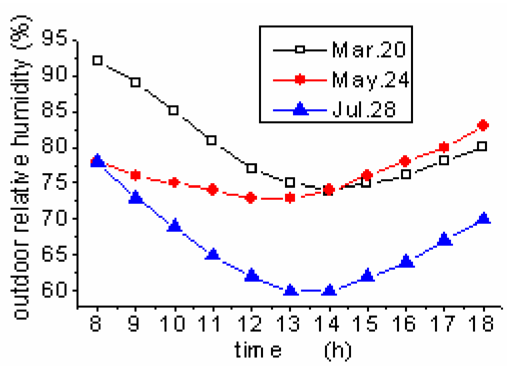

Fig.4 Variations of the outdoor relative humidity with respect to time

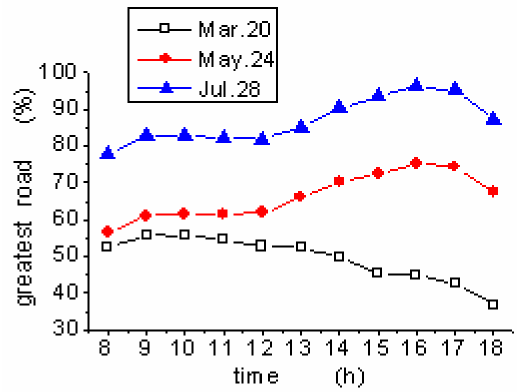

Fig.5 Variations of the greatest load rate with respect to time

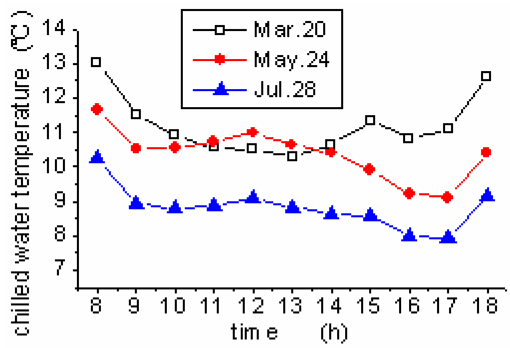

Fig.6 Variations of the chilled water temperature with respect to time

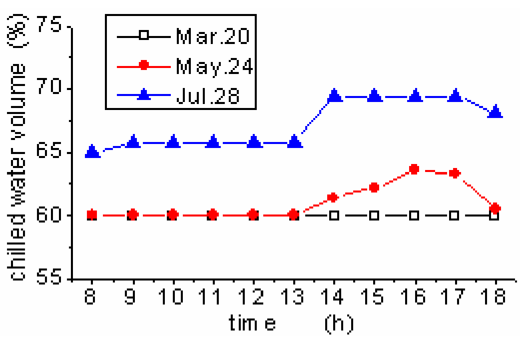

Fig.7 Variations of the chilled water flow with respect to time

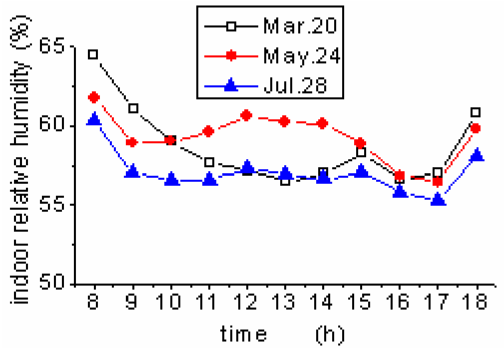

Fig.8 Variations of the indoor relative humidity with respect to time

Increasing of the chilled water temperature will reduce the dehumidifying capability of the air cooler to result in increase of indoor relative humidity. Over-high chilled water temperature may impact the comfort of air conditioning due to reduction of dehumidifying capability of air cooler. However, according to the air-conditioning design standards, the relative humidity of comfort air-conditioned space can vary between 40% and 65%.[5] Variations of the indoor relative humidity with respect to time is shown as figure 8, with top value 65% of the whole year while during the calculation process set the indoor dry-bulb temperature at 25 , and the optimization process will meet the comfort condition of the air conditioning.

4. POWER-SAVING ANALYSIS FOR OPTIMIZED OPERATION

In case of statistics of simulation, a power-saving effect will be shown in figure 9. For the figure 9, the less average cooling load of one month, more effective the power saving is. The highest power-saving rate appears in December, as 36.7%. Meanwhile, min. value rate appears in July, only 14.5%, and the annual average power saving rate is 22.4%.

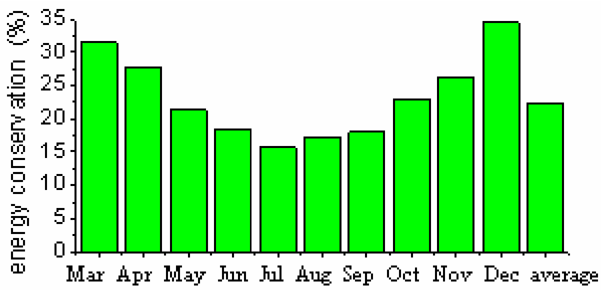

Fig.9 System power-saving effect scheme with coordinative optimization control

The performance of regulation is identified by comparison only; pump frequency conversion accepted mimic analysis of operation condition under same condition with power-saving effect as shown in Fig.10, annual average power saving rate is 17.5% only, it is obvious that optimization coordination of variable water flow and water temperature will open more power-saving space of air conditioning system.

A simulation of the air conditioning system in the same working condition only with pump frequency conversion was carried out. The statistics of the simulation results is shown as figure [10]. The annual average energy-efficiency rate is 17.5%. So a conclusion can be educed that the coordination optimization control with variable chilled water temperature and variable chilled water flow is better than that with variable chilled water flow only.

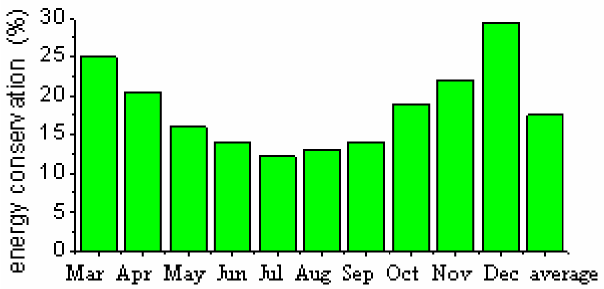

Fig.10 System power-saving effect scheme only with pump frequency conversion

5. CONCLUSION

The coordinative optimization control of air conditioning system based on variable chilled water temperature and variable chilled water flow will get better power-saving effect comparing with power-saving dependent upon frequency conversion of pump only. Case study for a commercial building in Guangzhou showed that the annual average power saving rate by the former control method is 22.4%, and the annual average power saving rate by the latter reaches 17.5%.

Increasing of chilled water temperature will reduce the dehumidifying capability of the air cooler to increase indoor relative humidity. The simulation showed that the optimization regulation process will satisfy the requirement for comfort of air conditioning system.

During optimization regulation process, the lower average cooling load rate is, the more obvious power-saving is. Max. value of average power-saving rate appears in December, as 36.7%. Meanwhile, the min. the rate appears in July, as 14.5% only.

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